Date 10/12/21

Experiment - 2

Exp. No. ....

Object- To draw the B-H curve for a ferro-magnetic material (a thin rod of soft iron) with the help of cathode ray oscilloscope and hence to determine the residual magnetism, coercive field and hysteresis loss.

Apparatus Required- Cathode ray oscilloscope, step down transformer of 6-12 volt, experimental thin rod of soft iron, a.c ammeter, rheostat, one resistor of 1 Ω, a resistance of 4.7 Ω, a variable resistance of 5 Ω, a condenser of 2 μF and a condenser of 1 μF, a hollow glass tube of light nearly 30 cm and diameter 3 cm with primary coil of insulated thin copper wire wound over it and a secondary coil of nearly 100000 turns wound on 10 cm length in its middle, screw gauge, connection wires.

Theory- When a magnetic material is magnetised by applying an external magnetising field H, the magnetic flux density (or magnetic induction) B produced within the material is related to the intensity of magnetisation I and the magnetising field H as

$$B = \mu_0 (H+I)$$

When a ferromagnetic material is magnetised by keeping it in an external magnetising field, we find that the intensity of magnetisation I gradually increases as the magnetising field H is gradually increased from zero. When the magnetising field H is zero, the value of

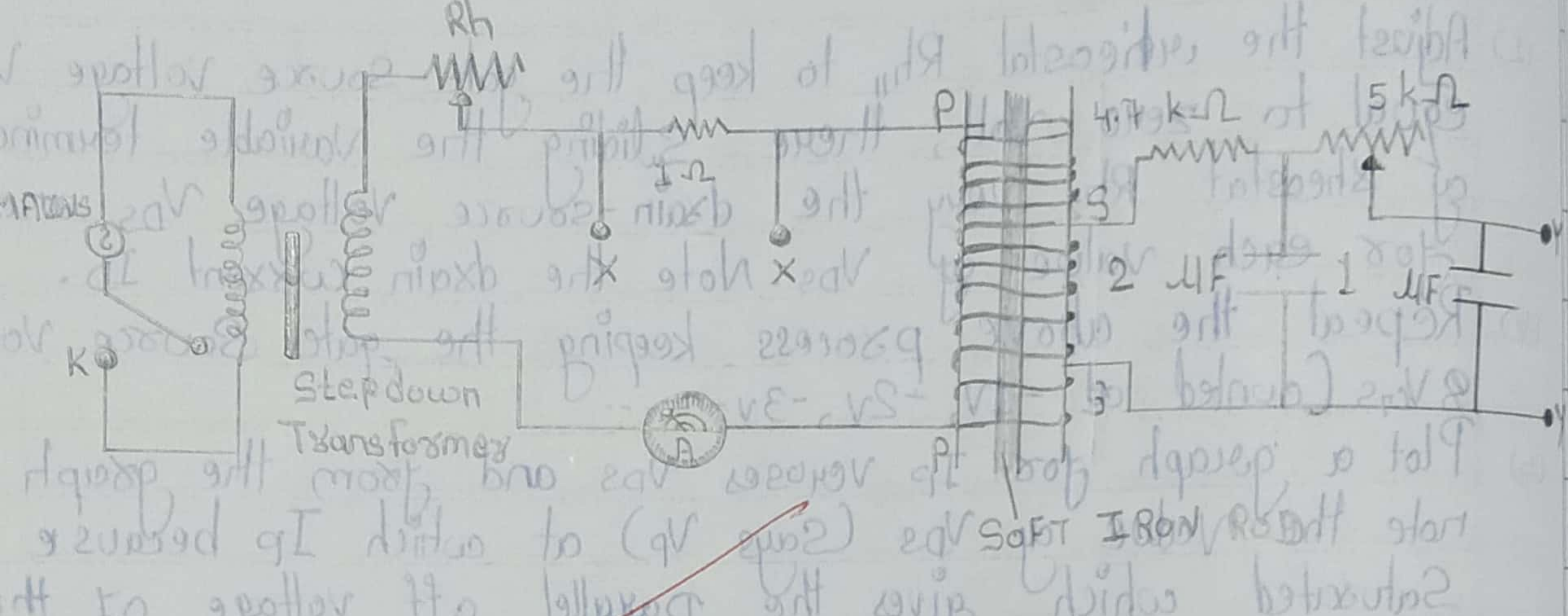


fig. 2. Electric circuit for B-H Curve

I is also zero. This position is represented by the point O. On increasing the value of H, the value of I increases in accordance with the path OA. When the value of H becomes H_{max} (corresponding to the point A), the value of I becomes I_{max} (saturated value of intensity of magnetisation corresponding to the point A). At the point A, the curve is nearly parallel to the H-axis.

Now if the value of H is decreased, we find the I-H curve does not follow the path AO, but it follows the path AB. When the value of H becomes zero, the value of I does not become zero, but it acquires some positive value (corresponding to the point B) i.e. Some intensity or magnetisation is left within the material even when the magnetising field becomes zero. This residual value of the intensity of magnetisation (= OB) is called residual magnetism and this property material is called retentivity.

Now if the magnetising field H is reversed and its value is gradually increased, the value of I follows the path BC and becomes zero at the point C. Obviously at the point C, the value of H is not zero. Thus to reduce the residual magnetism of the material to zero, an opposite magnetising field (corresponding to OC) has to be applied. This opposite magnetising field (which destroys the residual magnetism of the material) is called Coercive field and this property of material is called Coercivity.

Now if the magnetising field H is increased in the same direction, the substance gets magnetised in the opposite dirction and following the path CD, the intensity of magnetisation becomes maximum (= I_{max}) at the point D (where the value of H become H_{max}) i.e., the substance acquires the saturated value of intensity of magnetisation. Now if again the direction of magnetising field H is reversed (i.e, it is made in the initial direction), then again when the value of H becomes zero, the intensity of magnetisation does not become zero, but a residual magnetism (= OE) is left and when the magnetising field becomes OF (= Coercive field), the intensity of magnetisation becomes zero. On increasing the value of H again, the value of I increases and acquires the saturated value (corresponding to the point A) when H = H_{max}. Thus we get a complete cycle ABCDEFA of magnetisation which is called I-H curve or the hysterisis loop. From the equation $B = \mu_0(H+I)$, if the value of B is calculated for different values of I, and then a B-H curve is plotted, we find that B-H curve is identical in shape to the I-H curve. The only difference is that in the I-H curve, I acquires the saturated value. This property of lag of intensity of magnetisation I from the magnetising field H is called hysteresis.

Thus it is clear that when a cycle of magnetisation of a ferromagnetic substance is completed, some energy is wasted. This loss of energy is called hysteresis loss. This energy appears in form of heat energy in the substance. The energy lost per unit volume of the substance in a cycle is equal to μ_0 times the area of I-H curve or equal to the area of B-H curve.

Let number of turns per metre in the primary coil of solenoid be N. When an alternating current $i = i_0 \sin$ ~~or~~ ωt ampere flows in it, the magnetising field produced in solenoid is $H = Ni = Ni_0 \sin \omega t = N\sqrt{2}\, i_{rms} \sin \omega t$ ampere/metre.

Hence the maximum value of the magnetising field

$$H_{max} = N\sqrt{2}\, i_{rms} \text{ ampere/metre} \quad ①$$

If in the cathode ray oscilloscope, the total length along the X-axis is L_x cm when Y-gain is zero, then this length will express $2H_{max}$. Hence the calibration factor of the X-axis in terms of H is

$$C = \frac{2H_{max}}{L_x} = \frac{2\sqrt{2}\, N i_{rms}}{L_x} \; \frac{\text{ampere/meter}}{\text{cm}} \quad ②$$

In the cathode ray oscilloscope, let the total length along the Y-axis be L_y cm when X-gain is zero and while withdrawing the iron rod from the solenoid, half length $\frac{1}{2}L_y$ is doubled to L_y by the Y-gain till the entire iron rod comes out of the solenoid. Let Y-gain is increased n times for it and the length left in Y-direction at the last be h cm, then this length will be $h/2^n$ for its original amplification which will represent twice the maximum magnetic flux for the air core. If r cm is the radius of primary coil of the solenoid, then

$$2(\phi_{air})_{max} = 2\mu_0 H_{max} \times \pi r^2$$

∴ The Calibration term of Y-axis in terms of magnetic flux will be

$$A' = \frac{2(\phi_{air})_{max}}{h/2^n} = \frac{2\mu_0 H_{max} \times \pi r^2}{h/2^n}$$

Hence, the calibration term of Y-axis in terms of magnetic flux density B is

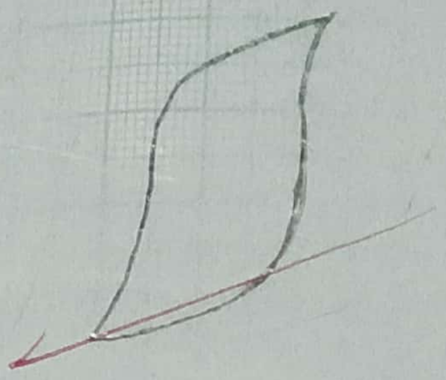
$$A = \frac{A'}{S} = \frac{2\mu_0 H_{max} \times \pi r^2}{(h/2^n)S} \text{ tesla/cm} \quad \text{—— ③}$$

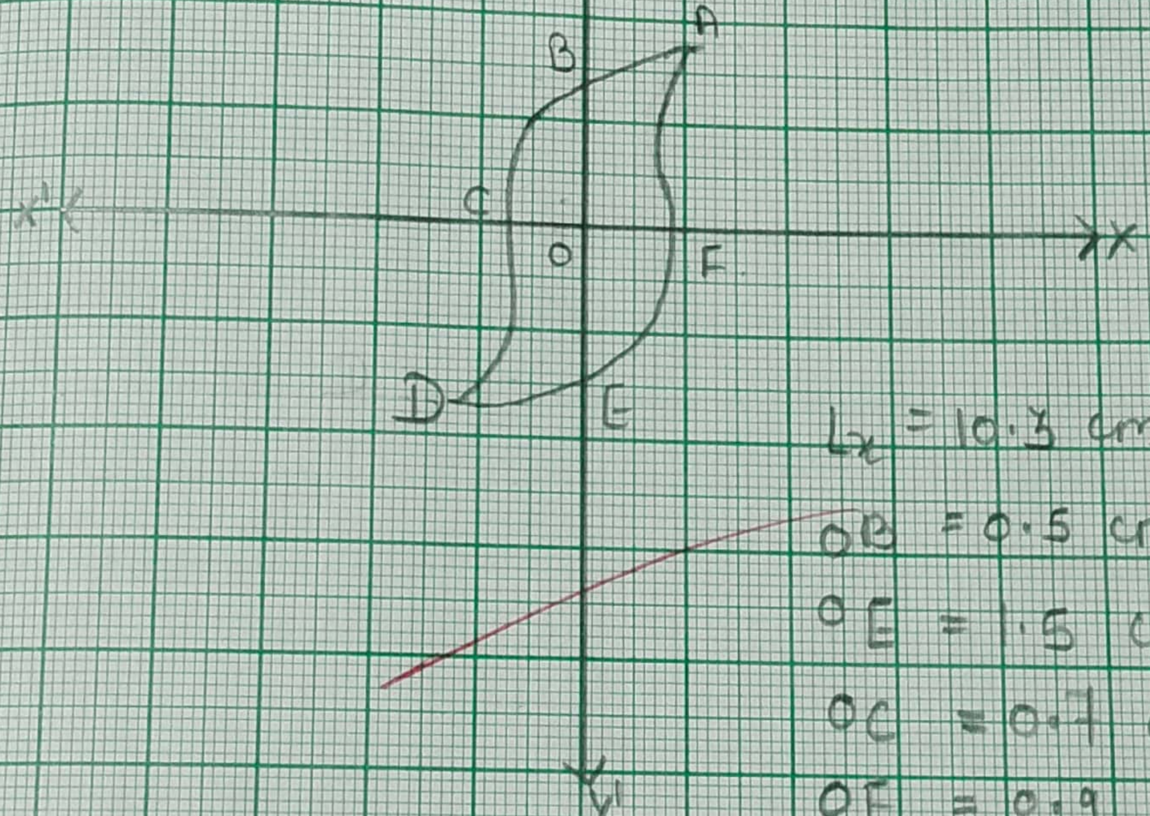
Thus eqn ② and eqn (3) represent respectively the values of H and B per cm along the X-axis and Y-axis of the Cathode ray oscilloscope. The B-H loop obtained on the Cathode ray oscilloscope is traced on a tracing paper and then drawn on a graph paper. From it, the length OB, OE, OC and OF are measured and the area of loop is measured by Counting the squared division on the graph paper. More than half square is Counted as full square, while less than half square is neglected while Counting it. Then

Residual magnetism $= \frac{1}{2}(OB + OE) \times A$ tesla

Coercive field $= \frac{1}{2}(OC + OF) \times C$ ampere/metre

and hysteresis loss = (Area of B-H loop) × A × C joule/m^3 Cycle.





$L_x = 10.3$ cm

OB = 0.5 cm

OE = 1.5 cm

OC = 0.7 cm

OF = 0.9 cm

Calculation-

Maximum value of magnetising field $H_{max} = N\sqrt{2}\, i_{rms}$ = ampere/meter.

Calibration term on x-axis

$$C = \frac{2H_{max}}{L_x} = \frac{2\times 1.9}{10.3}$$

$$C = \frac{3.8}{10.3}$$

$$C = 0.3689 \ \frac{\text{Amp/metre}}{\text{cm}}$$

Calibration term on y-axis

$$A = \frac{2\mu_0 H_{max} \pi r^2}{(h/2^n)S}$$

$$A = \frac{2\times 4\pi\times 10^{-7}\times 1.9\times \pi(0.005)^2}{8.2/(2)^6\times 1.86}$$

$$A = \frac{0.003746}{0.2383}$$

$A = 0.1571$ tesla/cm

Residual magnetism = $\frac{1}{2}(OB+OE)\times A = \frac{1}{2}(0.5+1.5)\times 0.1571$

=

= 0.1571 tesla

Coercive field = $\frac{1}{2}(OC+OF)\times C = \frac{1}{2}(0.7+0.9)\times 0.3689$

= 0.29512 Ampere/metre

Hystersis loss = (Area of B-H loop) × A × C

= 0.14198 joule/metre³ cycle.

Formula Used: $H_{max} = N\sqrt{2}\, i_{rms}$ A/m

Calibration term on X-axis $C = \frac{2H_{max}}{L_x}$ $\frac{\text{ampere/meter}}{\text{cm}}$

Calibration term on Y-axis $A = \frac{2\pi r^2 \mu_0 H_{max}}{(h/2^n)S}$ tesla/cm

Residual magnetism $= \frac{1}{2}(OB + OF) \times A$ tesla

Coercive field $= \frac{1}{2}(OC + OF) \times C$ ampere/metre

and Hysteresis loss = (Area of B-H loop) × A × C joule/m³ cycle, where N = number of turns per meter in the primary coil of the solenoid, i_{rms} = rms value of alternating current in the primary coil (i.e. ammeter reading), L_x = length along x-axis on the cathode ray oscilloscope when y-gain is zero, r = radius of the glass tube (or solenoid), h = length left along Y axis when x-gain is zero, on withdrawing the iron rod completely out of the solenoid, n = number of times y-gain is increased to double the length along Y-axis, OB, OF, OC and OF are the lengths in cm on the graph paper for the B-H loop.

Result - For the given ferromagnetic material (soft iron)

Residual magnetism = 0.1571 tesla

Coercive field = 0.29512 ampere/meter

Hysteresis loss = 0.14198 joule/metre³ cycle

Precautions - (1) During the experiment, the current in the primary coil of the solenoid must remain constant.

(2) The length of the iron rod must be equal to the length of the solenoid. If the rod is longer, equal lengths of it should project out of the two ends of solenoid.

(3) The rod should be gradually withdrawn from the solenoid.